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# Anatomical Variations of the Biliary System

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**ABSTRACT**

This concise abstract explores the anatomy of the biliary system, emphasizing normal structure and anatomical variations. The gallbladder, cystic duct, bile ducts, and pancreas collectively contribute to digestive processes. The complex intrahepatic and extrahepatic bile duct network is regulated by the sphincter of Oddi. Normal radiological views, as defined by Couinaud, underscore segmental anatomy. However, developmental variations may challenge accurate representation, potentially leading to surgical complications. Imaging methods such as computed tomography and ultrasound may fall short in revealing these variations, while endoscopic retrograde cholangiopancreatography offers precision at the cost of invasiveness and risks. The main focus is on anatomical variations, categorized as intrahepatic and extrahepatic. Intrahepatic variations involve duplications, atresia, and fusions of segmental ducts, while extrahepatic variations encompass duplications, atresia, and fusions of the cystic and common bile ducts. These variations, though often asymptomatic, can pose challenges during surgical interventions and may contribute to complications such as bile obstruction and infections. Understanding the anatomical variations of the biliary system is crucial for surgical planning and diagnostic accuracy, highlighting the importance of various imaging modalities in delineating these variations and optimizing patient care.

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## A. ANATOMY OF THE BILIARY SYSTEM

### Gall bladder

The gallbladder is an oval-shaped organ located below the liver. The gallbladder stores bile from the liver. Bile is a liquid that plays an important role in digesting fats. It consists of three parts: gallbladder, fundus, body and neck. The fundus is the largest part of the gallbladder. It extends to the anterior wall of the abdominal cavity and to the level of the ninth rib cartilage. The body is the middle part of the gallbladder. The neck is the narrowest part of the gallbladder. It is where the cystic duct exits the gallbladder (1-4).

The gallbladder is located in the right lobe of the liver, in the gallbladder fossa on the visceral aspect of the liver. The gallbladder is attached to the gallbladder fossa of the liver by connective tissue extensions. The upper surface of the gallbladder is devoid of peritoneum. Its lower surface is covered by the peritoneum, which covers the visceral surface of the liver. Neighbors of the gallbladder are; (i) anteriorly: Abdominal wall and 9th costal cartilage, (ii) posteriorly: 1st and 2nd part of duodenum, transverse colon, (iii) inferiorly: Hepatic flexure of the colon (3-6).

The arteries of the gallbladder arise from the cystic artery, which is a branch of the arteria hepatica propria. The cystic artery divides into two branches at the level of the gallbladder neck. The anterior branch is distributed on the lower surface of the sac, and the posterior branch is distributed on the upper surface of the sac, which is attached to the liver. Venous drainage of the gallbladder occurs through the cystic vein, which flows into the portal vein. Lymphatic drainage of the gallbladder is from the cystic glands in the neck of the gallbladder to the glands in the neck of the common bile duct. Here it anastomoses with the lymphatics coming from the head of the pancreas. The gallbladder is innervated by nerves coming from the celiacus plexus (1-3,6-8).

### Cystic Duct

The gallbladder duct is a duct that starts from the neck of the gallbladder and joins the main hepatic duct. The length of the gallbladder duct is 3-5 cm and its diameter is 3-4 mm. The gallbladder duct runs left and downward between the two leaves of the hepatoduodenal ligament. Meanwhile, it is located to the right of the a.hepatica propria and in front of the vena porta. The wall structure of the gallbladder duct is similar to that of the gallbladder. It contains mucosal plicae (Heister plicae). The function of the gallbladder duct is to transport bile from the gallbladder to the main hepatic duct. In this way, bile can be transported to the duodenum and digestion of fats can be achieved (9-11).

**Bile Ducts**

Bile ducts are channels that carry bile produced from the liver to the duodenum. Bile ducts are examined in two parts: intrahepatic and extrahepatic.

***Intrahepatic Bile Ducts***

Bile produced by liver cells is released into the intercellular spaces (bile capillaries). Several bile capillaries combine to form the intralobular ducts of the liver. These canals combine to form periportal canals. Periportal canals open into interlobular canals seen in the Kiernan space (spatium interlobulare hepatis). Segmental bile ducts are formed by the merging of the interlobular ducts. One segmental duct emerges from each liver segment. Segmental canals merge and decrease in number as they approach the porta hepatis. On the other hand, wall thicknesses and widths increase. As a result, right and left main hepatic ducts are formed. The right hepatic duct drains bile from the right lobe of the liver and the right half of the caudate lobe. The left hepatic duct drains the bile of the left lobe of the liver, the quadrate lobe, and the left half of the caudate lobe (1,2,9,12,13).

***Extrahepatic Bile Ducts***

The right and left hepatic ducts join just below the porta hepatis to form the common hepatic duct (ductus hepaticus communis). The common hepatic duct is approximately 4 cm (may range from 2-6.5 cm) long. It extends downwards within the hepatoduodenal ligament and merges with the cystic duct to form the common bile duct (ductus choledocus/biliaris) (1-3,10-13).

***Common bile duct***

The common bile duct is a channel approximately 7-10 cm long and 4-6 mm in diameter that carries bile from the liver to the duodenum. The common bile duct extends downward within the hepatoduodenal ligament. Hepatoduodenal ligament is a structure consisting of two layers of peritoneal sheets that connect the liver and the first part of the duodenum. Above the common hepatic duct and right-left hepatic ducts, ascending hepatic artery (a. hepatica propria) and its branches, lymph vessels, nerve plexuses and terminal right-left branches of the portal vein (v. porta hepatis) pass through the common bile duct. The common bile duct, as it passes through the hepatoduodenal ligament, consists of the following sections (14-18):

- ***Supraduodenal section***: It is the section located within the hepatoduodenal ligament.
- ***Retroduodenal section***: It is the section located behind the first continent of the duodenum.
- ***Retropancreatic section***: It is the section located behind the head of the pancreas.
- ***Intramural section***: It is the section located within the wall of the second part of the duodenum. The intramural section is the section located within the wall of the second part of the duodenum and opens into the papilla duodeni major, with or without merging with the ductus pancreaticus.

The intramural part of the common bile duct is enlarged in the part of the papilla duodenum and is called the ampulla of Vater. There is a structure called 'Sphincter of Oddi', consisting of smooth muscle fibers, around the ampoule of Vater. The sphincter of Oddi closes the common bile duct, allowing bile to be stored in the gallbladder and transferred to the duodenum when necessary (14-16).

**Sphincter of Oddi**

The common bile duct and the pancreatic duct join to form the ampulla of Vater before opening into the second part of the duodenum. Around the ampulla of Vateri, there is a structure called 'Sphincter of Oddi', which consists of smooth muscle fibers. The sphincter of Oddi is a sphincter that controls the common bile duct and pancreatic duct. When the duodenum is empty, the sphincter of Oddi is contracted and the channels are closed in this way. Bile fluid is secreted from the liver, fills the common bile duct and passes into the gallbladder. The cholecystokinin hormone is secreted under the influence of chyme passing into the duodenum. Cholecystokinin hormone causes the gallbladder and common bile ducts to contract. In this way, bile fluid is emptied into the duodenum (19-23).

**Pancreas**

The pancreas is both an endocrine and exocrine organ. The endocrine part produces hormones such as insulin and glucagon. The exocrine part produces digestive enzymes. The pancreas is located in the epigastric and left hypochondriac regions. It weighs approximately 70-100 g and its length varies between 12-20 cm, width 3-5 cm, and thickness 1-3 cm. Pancreatic Duct (Wirsung Duct) is the duct that carries digestive enzymes secreted from the exocrine part of the pancreas to the duodenum. The pancreatic duct extends from the tail of the pancreas to the head. It connects with the common bile duct located on the right side of the head of the pancreas. These two merging channels open into the second part of the duodenum. This opening site is called the ampulla of vater (23-27).

The pancreas is divided into three parts: head, body and tail. (i)The head is surrounded by the 1st and 2nd parts of the duodenum. (ii) The body is located behind the transverse colon. (iii) The tail is adjacent to the left kidney and splenic artery. The arteries of the pancreas are A. pancreaticoduodenales superiores, pancreaticoduodenales inferior and A. splenica. Veins are V. portae, V. splenica and V. mesenterica superior. The lymph nodes are odi lymphatici pancreatici, nodi lymphatici pancreaticoduodenales and nodi lymphatici mesenterici superiores. Its nerves are N. vagus and N. splanchnici (23-27).

## B. NORMAL RADIOLOGICAL VIEW OF THE BILIARY SYSTEM

The liver, defined by Couinaud, has a structure consisting of eight separate segments. Each segment has its own portal venous blood supply, hepatic venous and biliary ductal drainage system. The distribution of intrahepatic bile ducts is consistent with the segmental anatomy of the liver. The main hepatic branches form a tree system of segmental ducts that combine to provide drainage of the right and left lobes. The right hepatic duct follows a dorsocaudal course in VI. and VII. while the anterior ducts drain the segments V and VIII with a ventrocranial course. drains the segments. Right hepatic duct, left hepatic duct, II-IV. The combination of the duct draining the segments forms the common hepatic duct. This canal opens to the origin of the canal draining the caudate lobe and forms the common bile duct with the participation of the cystic duct more distally. The common bile duct joins the pancreatic duct and opens into the sphincter of Oddi in the second continent of the duodenum (28-33).

The biliary system may show developmental variations at intrahepatic or extrahepatic levels. These variations can cause ligation or resection errors that pose a risk of damage during surgical interventions. Additionally, stone formation in the bile ducts may increase the potential for the development of recurrent pancreatitis, cholangitis, and biliary malignancies. Nowadays, as liver resections and partial liver transplantations are performed more frequently, an accurate representation of biliary anatomy is important. Imaging methods such as computed tomography and ultrasound can often fail to demonstrate these anatomical variations. Examination methods such as endoscopic retrograde cholangiopancreatography accurately show the normal anatomy and variations of the bile ducts, but they have disadvantages such as being invasive, carrying the risk of serious complications, being operator dependent, involving ionizing radiation, and requiring the use of contrast material (30-35).

## C. ANATOMICAL VARIATIONS OF THE BILIARY SYSTEM

Biliary system variations are divided into two categories: intrahepatic and extrahepatic.

Variations were discussed under four main headings. These were grouped as follows: intrahepatic bile duct variations, extrahepatic bile duct duplications, cystic duct variations and others, respectively.

### Intrahepatic Variations

Intrahepatic variations are deviations from the structures of the bile ducts within the liver. Some of these variations are (28-34):

***Duplication of segmental ducts***: This is the condition when there are two bile ducts draining a segment. It is seen in 1-2% of normal anatomy. Duplication usually occurs in the right hepatic duct, but can occur in the left hepatic duct or both ducts. The exact cause of duplication is not known, but genetic factors are thought to play a role. Duplication usually does not cause any symptoms, but in some cases it can cause bile obstruction, infection, or other complications. The most commonly used method for the diagnosis of duplication is magnetic resonance cholangiography (MRCP). MRCP is a method that non-invasively images the bile ducts. Treatment of duplication depends on the symptoms.

***Atresia of segmental ducts***: It is a condition in which the bile duct draining a segment is completely or partially closed. It occurs with a frequency of approximately 1% in the population. Atresia usually occurs in the right hepatic duct, but can occur in the left hepatic duct or both ducts. The exact cause of atresia is unknown, but genetic factors are thought to play a role. Atresia usually does not cause any symptoms, but in some cases it can cause bile obstruction, infection, or other complications.

***Fusion of segmental ducts***: It is the union of bile ducts draining two different segments. Normally, each lobe and segment has its own drainage channel. However, in case of fusion of segmental channels, two or more segmental channels may merge to form a single channel. Fusion of segmental ducts is one of the most common variations in the intrahepatic bile ducts. It is seen in approximately 10-20% of normal anatomy.

### Extrahepatic Variations

Extrahepatic variations are deviations from the structure of the bile ducts outside the liver. Some of these variations are (31-40):

***Duplication of the cystic duct***: This is the condition in which there are two bile ducts that drain the gallbladder. This is a rare congenital anomaly of the biliary tract and occurs in 1-2% of normal anatomy. Duplication usually occurs in the right hepatic duct, but can occur in the left hepatic duct or both ducts.

***Atresia of the cystic duct***: It is a condition in which the bile duct that drains the gallbladder is completely or partially closed. It is a progressive and fibro-obliterating disease of the bile ducts in infancy. It usually affects children who show signs of bile obstruction within the first 3 months. Although its incidence is low, it is common worldwide and occurs in approximately 1 in 8,000-18,000 live births. Although the etiology and pathogenesis of the disease are unknown, it has two forms: congenital and acquired. The congenital form is less common (20%) and has syndromic associations. The acquired form may arise as a result of complex interactions between viral triggers and immune responses. This blockage can lead to liver damage and the development of cirrhosis, which can be fatal if left untreated.

***Fusion of the cystic duct with the common bile duct***: It is the union of the bile duct, which drains the gallbladder, with the common bile duct. This is one of the most common variations in the biliary tract and occurs in approximately 20% of the normal anatomy. In some cases, the cystic duct may join the common bile duct in an angular, parallel or spiral manner. Angular join is the most common shape and is seen in 75% of cases.

***Duplication of the common bile duct***: This is the condition in which there are two bile ducts draining the common bile duct. It is an extremely rare congenital anomaly of the biliary system.

It is usually characterized by the presence of a septum within the common bile duct or an additional common bile duct.

***Atresia of the common bile duct***: It is a condition in which the bile duct draining the common bile duct is completely or partially closed. It is a rare clinical condition but may have serious complications.

***Union of the common bile duct with the common bile duct***: It is the union of the bile duct, which drains the common bile duct, with the common bile duct.

Biliary system variations play an important role in surgical procedures and diagnostic evaluations. For example, it may increase the risk of damage to the bile ducts from accidental ligation or resection during cholecystectomy (removal of the gallbladder). Additionally, stone formation in the bile ducts may predispose to recurrent pancreatitis, cholangitis and biliary malignancies. Imaging methods such as computed tomography, ultrasonography, magnetic resonance cholangiopancreatography, endoscopic retrograde cholangiopancreatography and intraoperative cholangiography can be used in the diagnosis of biliary system variations (28-30, 37-40).

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